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RESEARCH AT THE STANFORD CENTER FOR RADAR ASTRONOMY

INTRODUCTION

The Stanford Center for Radar Astronomy (SCRA) is a joint venture of Stanford University (SU) and the Stanford Research Institute (SRI) to facilitate cooperative efforts (scientific, engineering and graduate student training) in radar astronomy and space science. The common interest in this field has grown out of basic and applied research programs at both groups for radar studies of the upper atmosphere and interplanetary space.

NASA grant NsG-377 funds have been used for a number of theoretical and experimental investigations in radio and radar studies of space plasmas (the interplanetary medium, the earth's magnetospheric wake, the solar corona, planetary ionosphere, etc.), lunar and planetary surfaces, communication theory, and spacecraft instrumentation. Of particular interest for the reporting period are two programs which have combined theory and experiment to yield new results and techniques.

The first of these is the completion of data analysis for the FM-CW Lunar radar experiment. The results are presented in full as Scientific Report no. 17 (NsG-377, SU-SEL 66-113). They are briefly summarized in this status report under the heading "Monostatic Radar Astronomy."

The second program involved the reception of Lunar Orbiter's S-band telemetry signals at DSN 12 using the station telemetry receiver driving a special 10 MHz phase-locked receiver. Analysis of the data on magnetic tape at Stanford has revealed that, as expected, both a signal direct from Orbiter and one reflected from the lunar surface are present in the IF passband. The initial results were described in a letter report on 19 October, 1966. Further data reduction is underway in an attempt to produce a one-dimensional hologram of the lunar surface.

PLANETARY RESEARCH

In the following section, individual graduate students and research associates have given brief reports of activity during the period.

Monostatic Radar Astronomy

The analysis of lunar chirp-radar echoes obtained on 6- and 12-meters to determine the angular scattering properties of the moon's surface continued as described in previous reports. More effort was spent attempting to fit reduced data to theoretical models of the scattering law than in reducing any more data during this period. Although a number of schemes and variations for fitting the data to the model were tried, there was no really satisfying result. Problems encountered include difficulty in determining the background noise level, to which the fitting process is very sensitive, and doubts about the validity of the theoretical scattering formula at these wavelengths and small angles.

It was decided to analyze more data more extensively to obtain better resolution (i.e., more data points per range interval), a better estimate of the noise level, and smaller variance in the estimate of the power scattered in each range interval. This required a great increase in the computing effort with the techniques used up to now. However, a new algorithm for computation of frequency spectra which allows an extreme reduction in computing time has recently come to attention and will permit this to be easily accomplished.

A section of data which met the requirements of a wide section of echo-free frequencies for an accurate noise level determination, a small rate of change of the frequency of range intervals (Doppler plus integrated range), and good signal strength, was located in the Rayspan records and digitized onto magnetic tape. A program is currently being written to do the analysis. Simultaneously, the theoretical considerations are being investigated for the purpose of obtaining a fit to the data.

Planetary Surface Mapping

The collection and initial reduction of surface bounce data from Lunar Orbiter I has continued. At the moment, we have no final results, but we have detected the bounce signals and located some of the features on the moon's surface.

In the past 6 months, we have developed methods for converting r.f. data into a one-dimensional hologram and have been successful in the reconstruction of simulated data. The techniques which have been developed are being applied to the processing of the Lunar Orbiter I data.

Optical Analysis of Radar Images

It was the objective of this part of the program to investigate a number of important problems connected with the proposed method of mapping planetary surfaces. This method, which involves an extension of optical techniques of wavefront reconstruction, makes use of a bistatic radar between the earth and a spacecraft orbiting a planet to obtain the microwave data and then employs optical methods for the reconstruction of the image.

In the course of this program, an optical system was developed which permits the conversion of digital data to precise density variations on a photographic plate. The high resolution spectroscopic plate is placed on a uniformly moving platform whose exact motion is monitored by a laser. This laser output is used to control the rate of a computer output so as to achieve a very accurate recording rate on the plate. The data from the computer is converted from digital to analog form and is used to modulate the intensity of another laser whose output is passed through a narrow slit and carefully focused on the high-resolution plate. In this way, digital information on a magnetic tape which, for example, may be the radar signal along a satellite orbit, is converted to density variations along a line on the photographic plate. After the recording and developing processes, the hologram may be illuminated with a laser beam in order to obtain a reconstructed image.

This optical-computer system was successfully used to record point sources (from a tape of calculated data) on spectroscopic plates. Then, reconstruction of these artificial points were obtained by using conventional reconstruction and spatial-filtering techniques.

In the current work in this program, data that was obtained from actual radar information of the moon's surface from a lunar orbiter is being employed in the recording and reconstruction experiments.

Planetary Atmosphere and Ionosphere

The analysis of the Mariner 4 radio occultation data has been continuing during this reporting period. In particular, the effects of the atmosphere on the S-band amplitude have been studied in greater detail. Further preparations have also been made for the radio occultation measurements to be made during the Mariner-Venus 67 mission.

There are two schools of thought with regard to the atmospheric pressure near the surface of Venus. One group of workers explain the wavelength dependence of the microwave emission from Venus in terms of a dry atmosphere with a surface pressure of several hundred atmospheres. The other group assumes that the high microwave temperature is caused by a greenhouse effect due to large amounts of water vapor. For the latter models, the total pressure at the surface of Venus is on the order of 10 atmospheres.

Surface pressures on the order of a hundred atmospheres are too high to permit tangential penetration of the radio links all the way down to the surface. Thus, for these atmospheric models, neither the dual-frequency nor the S-band 1967 occultation experiments would yield surface pressure. For the low pressure models, on the other hand, both of the dual frequencies (50 and 425 Mc/s) should at least be able to penetrate down to the surface on the night side of the planet where the ionospheric refraction is expected to be small. The S-band signal, on the other hand, may, in this case, be absorbed by water vapor before it has reached down to the surface.

A calculation of the Venus echo strengths was made with the Arecibo Ionospheric Observatory radar on 40 MHz and 430 MHz on the date of the Mariner 67 flyby of Venus in order to make an independent measurement of the ionospheric pulse delay. It is our conclusion that the sub-radar point will have been in prolonged darkness and the Venusian ionospheric effect will not be easily measurable. Nevertheless, an earth-based radar measurement should be scheduled for this date, which, due to Arecibo antenna limitations, will occur about 4 hours before the flyby of Venus.

To acquire an adequate background for work on the proposed Preliminary Study of Atmospheric Density Measurements by Means of Satellites (Proposal no. RL 23-66), a literature survey on several related subjects was undertaken by one student and rough preliminary calculations were made. Familiarization with the project consisted of studying the proposal itself and sections in the SPINMAP Final Report (the basic idea of measuring the Earth's atmospheric density by occultation experiments with satellites is considered here).

Due to the general nature of the information given in the SPINMAP Report, time was necessarily spent duplicating and verifying the calculations in the report and finding out many of the details which were omitted. Rough calculations were made in the following areas: 1) simplified orbit determinations, 2) transponder receiver and transmitter requirements, 3) approximate "path-defect" due to presence of atmosphere and the corresponding Doppler shift introduced by it, 4) effects of water vapor on measurements, and 5) the determination of optimum frequency for experiment. Other possible problem areas which arose are being investigated now.

Signal Processing

We have just started the development of a data processing package for high speed Fourier analysis and convolution for general use. Investigations were made of faster digital spectral analysis using the Cooley-Tukey algorithm (Fast Fourier Transform) and outboard digital hardware. Our conclusions are that although the optimizations are far from being fully explored, both techniques can increase the number of spectral points per dollar by about a factor of 10 to 100, especially for small-sized optimally configured computers.

Solar Radar Program

During the summers of 1963, 1964 and 1965, a total of about 200 attempts were made to obtain radar reflections from the solar corona. A frequency-shift-keyed signal near 25 MHz with a basic 4 second pulse length was used in all attempts, with the frequency shift being 12, 40 and 50 kHz, respectively. The veracity of the entire system has been proven by thorough analysis, test runs, and the use of most of the equipment in comparable radar investigations of the moon.

Within the sensitivity of the system, no radar returns have yet been detected in any of the data. The present conclusion is that the average radar cross-section of the sun was less than one photosperic area during all three data periods.

Present effort is being devoted to salvaging much of the data previously felt to be of no value. Also, since the effective system sensitivity can be improved by the summation of the data from many individual trials, preparation is under way to sum all of the data obtained to see if a return can be detected in the composite data.

SPACECRAFT TECHNIQUES

Signal Channel Coding Schemes

The optimum set of waveforms for binary signal communication in white noise is an antipodal set; that is, binary "zero" and "one" are transmitted as RF waves with relative phase 0° and 180°, respectively. Optimum demodulation of phase-modulated signals requires some sort of coherent reception which implies the use of phase-locked loops in the receiver and demodulator. A phase-locked loop requires a steady carrier to lock on, but there is no carrier component present in the antipodal signals described ablve. At present, a pilot carrier is transmitted to provide phase information for the receiver, but such a carrier consumes an appreciable part of the available transmitter power so that it would be desirable to dispense with it.

A carrier may be derived at the receiver by [illegible] processing of the carrier-less [illegible]

It is known that non-linear processing degrades the signal-to-noise ratio when the signal-to-noise ratio is small (as it usually is in space communication). However, some questions are: How much degradation occurs for a given non-linear process? How much can be tolerated? Can a system be built to operate at the frequencies used by experimenters?

A survey of the literature is being conducted at present to see if any of the answers are already available. A memorandum will be prepared shortly summarizing these findings.

We are also exploring finite-state theory with hopes of gaining insight into methods of generating codes which are applicable to deep-space tracking and related problems.

Receiving Techniques

During the past six months, work continued on the switching bandpass filter project. This filter was described in full in the last report, but briefly, it uses multiple paths, each containing sampling switches and low-pass filters to obtain a bandpass characteristic. It has the characteristic that its center frequency is electrically tunable. Using active RC filter techniques, it is also possible to electrically tune the bandwidth of the filter.

A filter was constructed with a center frequency of [illegible] [illegible]. It used analog multipliers for down conversion and transistor switches for up-conversion. The constructed [illegible] have been adequate for FM or PM but distortion in the analog multipliers caused modulation of the output which would have been detrimental in an AM system. Also, phase shifts in transistor stages made the unit hard to tune.

A new unit is being designed and will soon be constructed. The new unit will use analog switches both for up-conversion and down-conversion. It will also have digitally generated timing and phase shifting. It will be constructed with modular techniques so that individual sections may be easily replaced.

A computer program is being prepared to simulate the filter. Since any amplitude and phase errors are cumulative, it is hard to isolate their source. A computer simulation should aid in error analysis.

The biggest problem left to be solved before we can have a filter on a chip, is the design of a low-pass filter which can be integrated. Active RC networks can eliminate the inductance problem but, except for wide-band applications (150 kc), the values of capacitance required by the low-pass filter are too large to be integrated using present techniques. Until larger values of C are available in integrated circuits, the low-pass filters will require hybrid techniques.

Electron Density Determinations

An evaluation is being made of a new method to determine where electron density variations occur along a propagation path. The method uses a two-way radio link, that is, a ground-based transmitter at frequency f_u, a coherent satellite transponder transmitting at f_d (f_d is near f_u), and a phase-locked receiver at f_d. An auto-correlation of the receiver static phase error is performed to determine where the density variations occur along the propagation path.

A statistical analysis of the method with respect to signal bandwidth and the number of resolution cells along the propagation indicates that the method is feasible. The dispersion problem caused by the motion of the earth and satellite has also been studied. In general, it causes a small loss in the signal-to-noise ratio.

In June of 1966, some preliminary data for evaluation purposes was recorded at Stanford using the 136 Mc R and RR signals from the IMP satellite. A DEI receiver with a phase detector (a multiplier) range of $\pm 180^\circ$ was used. Phase excursions greater than 180° would cause foldover and make the data useless. The evaluation results were as follows:

1) The effects of the medium were larger than the receiver phase jitter.

2) A histogram of the data did not show any foldover.

It was also observed from the geometry of the Rosman-to-IMP-to-Stanford radio path that the Fresnel zone overlap was very small. A much closer transmitter-receiver arrangement is necessary.

A data source at S-band frequency appears to be the Pioneer VII satellite. The ground receiver and transmitter are often at the same site and the static phase error is routinely recorded for other purposes. Some of this data is currently being evaluated to see if effects of the medium can be observed above the receiver phase jitter.

Some work is also being done to synthesize the effects which we hope to measure in the propagation medium. A digital computer program has been written to compute the effects of a gaussian-shaped plasma cloud on the received signal. Eventually, it is hoped, a random collection of plasma clouds can be placed in the propagation path and their effect on the received signal can be computed. This will aid in understanding and interpreting the measurement results.

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Dyce, R. B., "Solar Corona Effects on Planetary Radar Echoes Observed near Superior Conjunction," presented at Fall URSI Meeting, Commission V, Palo Alto, California, December, 1966.

Lusignan, B. B., "The Design of Space Experiments as an Educational Process," presented at the Fall URSI Meeting, Joint URSI/G-AP Technical Session, Palo Alto, California, December, 1966.

BUDGET

The total amount awarded for research grant NsG-377 for the four-and-a-half year period from 1 January 1963 to 30 September 1967 is $809,000. As of 31 December 1966, $718,921 has been expended leaving a balance of $90,079.

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